ARMY RESEARCH LABORATORY

XM194 Gun Mount Shield: Processing in a Female Tool Utilizing Embedded Sensors for Process Control

by William O. Ballata, J. Robert Klinger, and Shawn M. Walsh

ARL-TR-1710

July 1998

Abstract

This report addresses the use of U.S. Army Research Laboratory (ARL) and industry technologies to prototype the XM194 gun mount shield. The prototyping was done with novel ideas and techniques in mind. It was used as an advanced technology demonstrator for sensor-based process control. First, a brief description of the XM194 gun mount shield is given. Second, Seemann's Composite Resin Infusion Molding Process (SCRIMP) was used as a fabrication process, which is possible through the establishment of a Cooperative Research and Development Agreement (CRADA) with SCRIMP Systems, Inc. Third, the state-of-the-art Sensors Mounted as Roving Threads (SMARTweave) system is detailed, along with the sensor-based control methodology utilized in the process. Fourth, the successful processing of the XM194 gun mount shield is illustrated. Finally, several possibilities for future sensor process and process control work are discussed.

Table of Contents

INTENTIONALLY LEFT BLANK.

List of Figures

INTENTIONALLY LEFT BLANK.

1. Introduction

The prototyping of the XM194 gun mount shield was done with novel ideas and techniques in mind. It was used as an advanced technology demonstrator for sensor-based process control. Seemann's Composite Resin Infusion Molding Process (SCRIMP) was used as a fabrication process. This report addresses the following points. First, a brief description of the XM194 gun mount shield is given. Second, SCRIMP, which is possible through the establishment of a Cooperative Research and Development Agreement (CRDA) with SCRIMP Systems, Inc., is described. Third, the state-of-the-art Sensors Mounted as Roving Threads (SMARTweave) system is detailed. Fourth, the actual processing of the ballistic shield is illustrated. Finally, several possibilities for future work are discussed.

2. XM194 Gun Mount Shield

The XM194 gun mount shield, as shown as part of the 155-mm, advanced, solid propellant, armament system in Figure 1, is composed of an S2-Glass composite armor. This component was designed as composite material and has some structural requirements, but its primary purpose is ballistic. The shield protects the cooling and recoil mechanisms. The intentions of this project were to prototype the "ballistic shield."

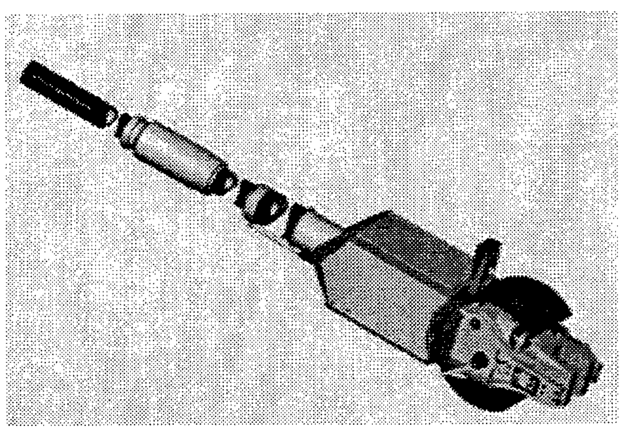

Figure 1. The 155-mm, Advanced, Solid Propellant, Armament System, Including XM297E1 Cannon Assembly, Laser Ignition System, and XM194 Gun Mount.

The XM194 gun mount shield is part of a customer project, but would also be an advanced-technology demonstrator for an embedded-sensor system called SMARTweave and proof of concept for SMARTweave-based process control.

3. SCRIMP

For this program it was decided to utilize a new, low-cost, resin-transfer-molding operation (RTM) called SCRIMP [1]. This is a low-cost process for several reasons: (1) the tooling is one-sided; (2) the raw materials used are relatively inexpensive; (3) the preforming could be automated; and (4) it is a room-temperature process, negating the necessity of large, costly ovens. The process has proven to have excellent performance. First, volume fractions of 55% have been demonstrated. Second, the process utilizes vacuum to drive the flow, which results in very low void content. Third, the process is versatile and can easily incorporate complex geometry and multiple insertion materials (e.g., three-dimensional [3-D] truss structures). Finally, SCRIMP is very economical for producing thick-section composite materials. All of these advantages make SCRIMP an excellent choice for many Army applications. A typical schematic of SCRIMP is shown in Figure 2.

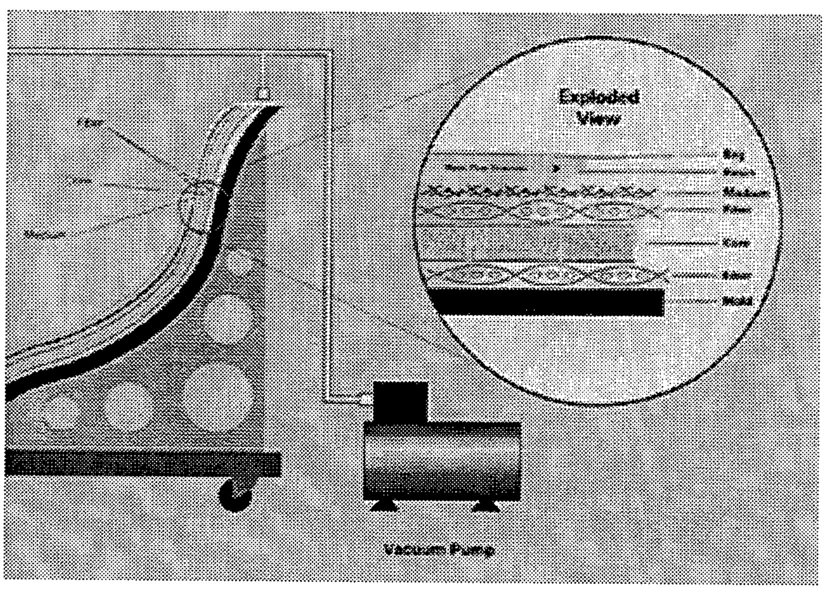

Figure 2. A Schematic of SCRIMP, Courtesy of Seemann Composites, Inc.

SCRIMP is a process that is currently manual in nature. The preform manufacturing and the resin mixing are done by hand. The process is controlled by an experienced engineer. Currently, SCRIMP is an "art" not a science. However, new research on SCRIMP is geared toward automating or computer-controlling several steps of the process. The closest component to computer control is the resin mixing. In fact, a machine is being manufactured by Accudyne, for Hard Core DuPont, that will mix all the resin components in line to exact quantities. This advancement will allow for variable resin contents throughout the component in an effort to minimize exothermic reactions. Another advancement could be preform manufacturing. Mass production of preforms is possible; however, it has not been emphasized because SCRIMP is currently used in low-volume manufacturing. This could be done if higher production rates are required.

The most difficult process automation to address is the infusion process itself. Simple infusion schedules can be automated but are often not optimal. The difficulty arises when the infusion is to be optimized. Optimization can be done by the process designer using Darcy's law for flow approximation in a finite element environment. These models and their validation are being researched in the academic world. True optimal processing could be accomplished by monitoring the flow-front progression and comparing it to an optimized-flow model, then basing control decisions to force the flow front to follow the optimal path. Based on the flow-front state, control algorithms exist to control many things, like flow rate, temperature, and pressure. The ability to control the process still hinges on the knowledge of where the flow front is. That is where SMARTweave comes into play.

4. SMARTweave

SMARTweave has undergone a series of innovations since it was first patented [2]. The SMARTweave system consists of two planes of conductive threads in an orthogonal, noncontacting grid. The two layers are separated by plies of insulative preform. A 12-V, direct-current (DC) signal is sent through one of the planes of sensors, which are called the excitation lines. The second plane of sensors, called the sense lines, measure the current that passes through the junction. Figure 3 depicts the general circuit schematic for the SMARTweave system.

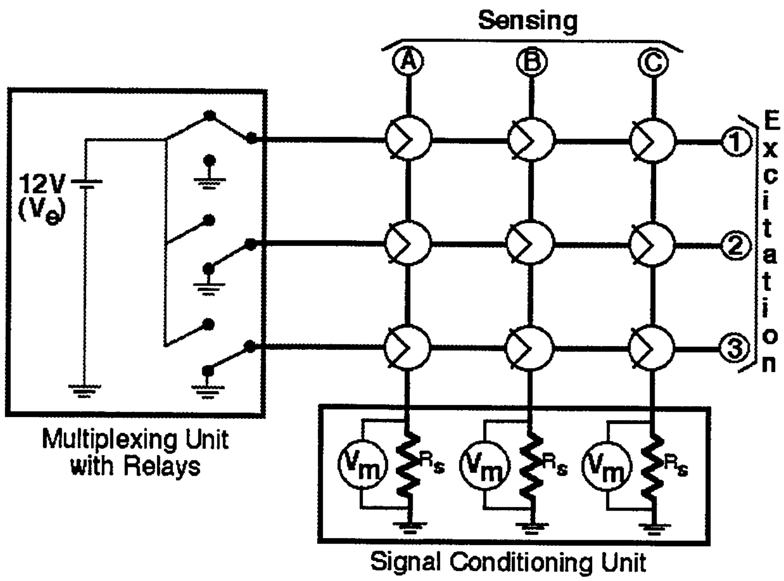

Figure 3. SMARTweave Circuit Schematic Depicting a 3-Excitation × 3-Sense Line Grid.

The polymeric resin material, which serves as the matrix for the composite, contains ions that are free to move within the fluid. SMARTweave utilizes this fact, and, as the resin fills the preform, the two planes of sensors form a series of connected circuits. The sense lines measure the voltage that can cross the gap between the two planes. Since a DC current is utilized, only the ionic mobility of the resin is being measured. Therefore, the resin acts as a variable resistor, and, the lower the resin resistance, the higher the overall SMARTweave signal.

The SMARTweave system consists not only of the electrical sensing grids but also of a series of hardware and software components. First, a signal-conditioning unit, which was custom made for the U.S. Army Research Laboratory (ARL) by Waibel Technical Computing (WTC), contains the 12-V, DC power supply, as well as the mechanical relays used to switch from one excitation line to another. A National Instruments SCXI-1000 Chassis with a 1300 module controls the sense lines. A Dolch L-PAC 586 portable computer is used to collect and analyze the data. The software that acquires the data runs on National Instruments LabVIEW Version 3.0.

The user is faced with five main options upon entering the SMARTweave software package, as depicted in Figure 4. The sampling rate may be defined in the grid. At this point, the system has a maximum capacity of a 16-excitation × 16-sense lines, for a total of 256 nodal locations. However, not all sensors must be utilized at once. In the faces option, the user may define not only the number of sensors to collect data but also the geometry of the grid orientation and nonexcited nodes. Figure 5 illustrates the typical flow screen seen by the operator. In this case a 6-excitation × 6-sense grid has been chosen, where each block corresponds to a specific voltage at the respective node. The flow front of the resin may be depicted on this flow graph. Not only can one view the overall picture of the resin infusion, but one may also focus upon the voltage value at individual nodes using the grid probe. The cure graph displays real-time voltage vs. time data for any series of user-defined node combinations. The logging period, file name, and elapsed time are displayed on the FLOW screen. The elapsed time may be defined to correlate with any zero time, such as initial point of infusion or addition of the catalyst in order to judge time until gelation. The SMARTweave FLOW screen also allows the user to transfer real-time-voltage data across the internet. This allows for advanced numerical analysis, using a Silicon Graphics (SGI) Workstation in real time.

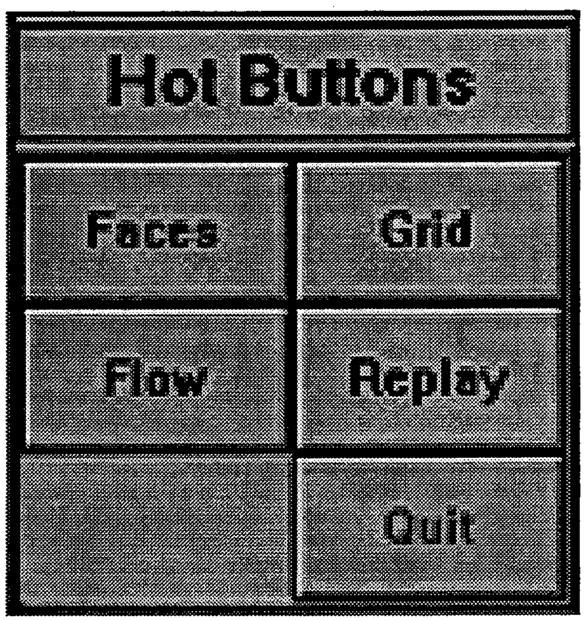

Figure 4. Five Main Options Upon Entering the SMARTweave Software Written on LabVIEW 3.0.

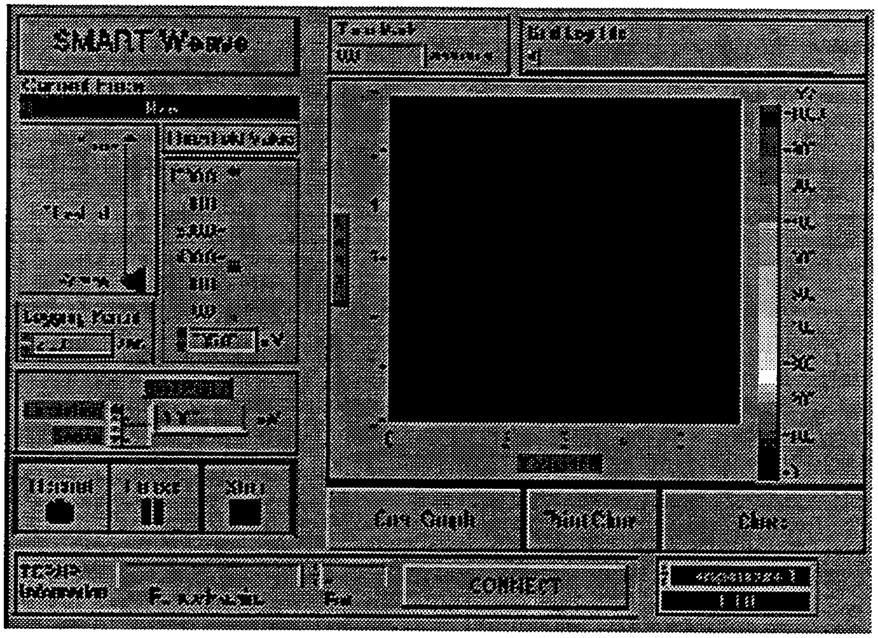

Figure 5. The Real-Time Voltage Data May Be Viewed, Recorded, and Transferred Over the Internet in the FLOW Option.

Once the data have been recorded, the portable system has the option of replaying the data at any time. As Figure 6 shows, the replay screen has many of the same features as the FLOW screen, including overall flow grid, grid probe, and cure graph. In this example, a point infusion and line vacuum source along the last excitation line were tested. SMARTweave monitored the semicircular flow pattern induced by the experimental setup using glass preform and an epoxy resin. The data may also be exported in any format with a defined amount of data points. Another feature of the replay screen is the ability to view thermal profiles recorded using a series of thermocouples, which are independent of the SMARTweave grid.

There are numerous applications of the SMARTweave system in the area of process control of composite materials manufacturing and damage detection. It is particularly beneficial to have the ability to visualize the resin flow front in RTM and other two-sided tooling processes. Often, complex geometric shapes provide a greater risk of forming dry spots or areas that are not fully wetted by the resin. With the use of SMARTweave, the flow front may be visualized during the infusion process. With such on-line techniques, many changes could be made during the infusion

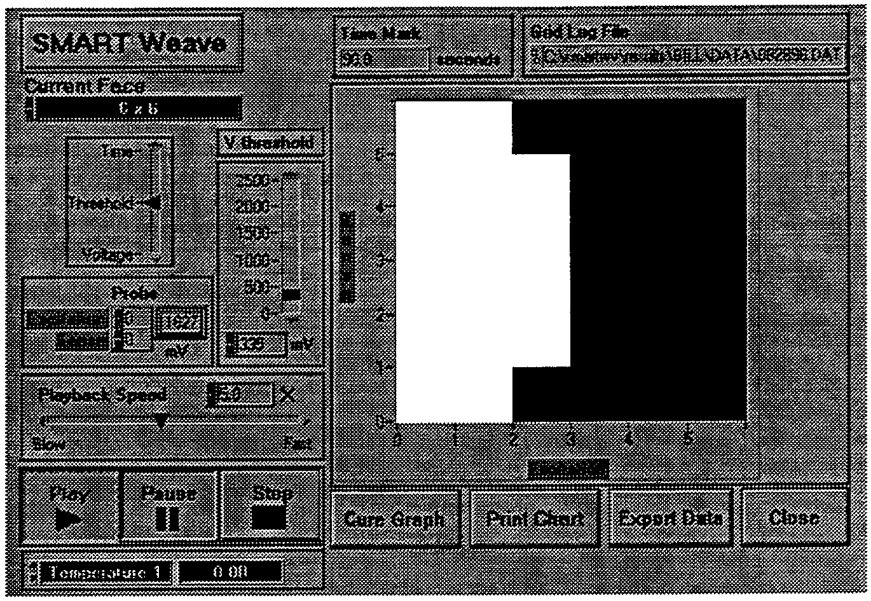

Figure 6. The REPLAY Option Allows One to View, Print, or Export Previously Recorded Data.

to ensure full wetting of the part, such as altering inefficient vacuum ports, increasing incoming fluid flow, and adjusting pressure. By knowing the geometry of the sense lines, the resin position may be correlated with time. Such information allows the user to estimate the overall filling time by calculating the incoming resin velocity. Flow simulations may also be verified with the correlated time vs. position of resin data that the system records. The capability to visualize the flow of resin throughout the thickness of the part provides numerous applications in the area of process control.

Research is ongoing at the University of Delaware's Center for Composite Materials to relate the voltage signal to the cure of the polymer. Since a DC voltage is used to measure the ionic mobility of the fluid, the extent of cure can be monitored by comparing relative voltages. During the cure of thermoset resins, crosslinking of the polymer chains occurs. The increase in crosslinking density results in diffusion limitations of the ions. As the ionic mobility becomes restricted, the corresponding voltage signal is reduced. The change in voltage signal output may be used to relate the change in viscosity of the resin, assuming a constant temperature. Such significant information is crucial for SCRIMP, since the time of infusion is limited by the resin viscosity. The extent of cure of the system may be monitored using similar techniques. Predicting the extent of cure of the part in-process allows an accurate determination of demold time. In doing so, a higher production may be achieved and therefore result in a more economical use of the tooling.

The embedded sensors may also be utilized after the infusion process is complete. ARL is investigating the possibility of SMARTweave as a damage-detection mechanism. A conductivity test may be conducted along the sensors both before and after the part is ballistically impacted. As the part is damaged, delaminations are created throughout the part causing the sensor/matrix interface to separate. A comparison of the resistances along the sensors allows one to correlate the extent of impact. This ability would be best served with a sensor material whose resistance is sensitive to strain.

SMARTweave may be used over a range of fluid resistances. As one might expect, the lower the resin's impedance, the higher the initial voltage. Applied Polyamic's SPH4, a low-impedance phenolic resin has been tested in the crew capsule of the composite armored vehicle (CAV). Applied Polyamic's SC4 moderate-impedance Epoxy system was applied in the lower hull of CAV. Most of SMARTweave's experimentation has been performed using vinyl ester, or high-impedance resins. Specifically, over 50 flat plates have been produced, which incorporated both mechanical and chemical characterization for SMARTweave. Dow's Derakane 510a-350, 2.0 weight-percent, Akzo's Trigonox 239A, and 0.2 weight-percent Mahogony's CoNAP were in the fabrication of the ballistic shield.

Figure 7 depicts an example of the previously discussed cure graph for the SC4 epoxy system. Additional thermal energy was required to fully cure this epoxy system. Therefore, SMARTweave's data were used to monitor not only cure changes but also temperature fluctuations. Initially, the resin was infused into the part at room temperature, as shown by the sudden increase in voltage at time zero. The sudden decrease in slope was caused by parallel circuit creation as the part filled. The voltage stabilized as a steady state was reached, indicating the part had been fully wetted out. At this point, the tool's temperature was increased to 60° C. The SMARTweave signal followed this change, since viscosity of the resin decreased with increasing temperature, as indicated by the first increase in slope. The second steeper rise in the voltage signal was caused by the autocatalytic

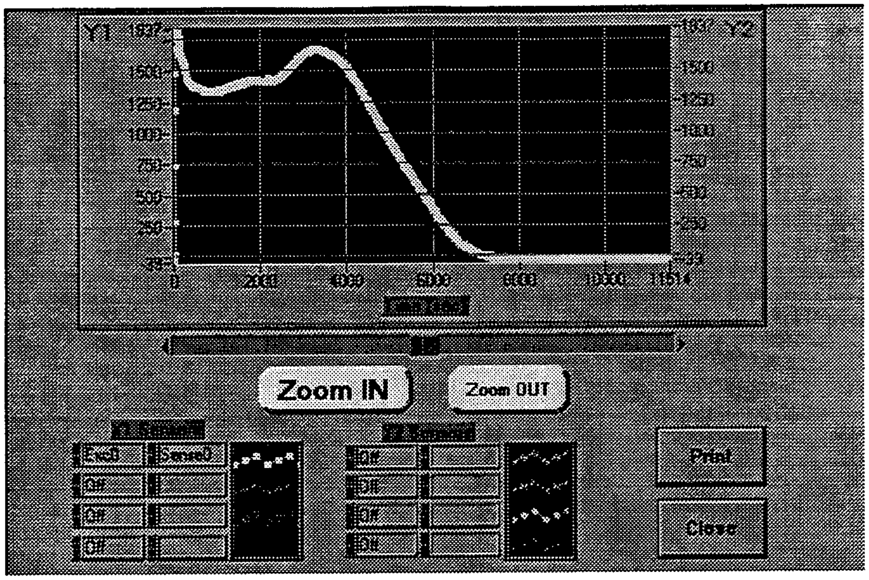

Figure 7. Cure Graph Represented as Voltage vs. Time for SC4 Epoxy System. The Part Was Infused at Room Temperature and Then Ramped to 60° C at 1,200 s. SMARTweave Monitored the Change in Temperature as Indicated by the Varying Voltage Signal.

(exothermic) reaction of the resin. The top of the peak indicates where diffusion limitations began to take over. At this point, the ionic mobility was limited due to extensive crosslinking, and the sensed voltage began decreasing at a constant rate.

5. Processing of the Ballistic Shield

The most recent application of the SMARTweave system was in the production of prototype XM194 Ballistic Shields, as shown in Figure 8. The ballistic shield protects the recoil and cooling mechanisms of the 155-mm cannon. The female tool, as illustrated in Figure 9, was used in conjunction with SCRIMP to manufacture the shield. Since the part is considered a thick-section composite, the resin-flow front needed to be monitored at the surface of the tooling. Therefore, 16-sense lines were placed three layers above the mold surface. Next, two layers of the glass fabric were laid down to separate the sensor planes. Then 16 excitation lines were placed orthogonal to

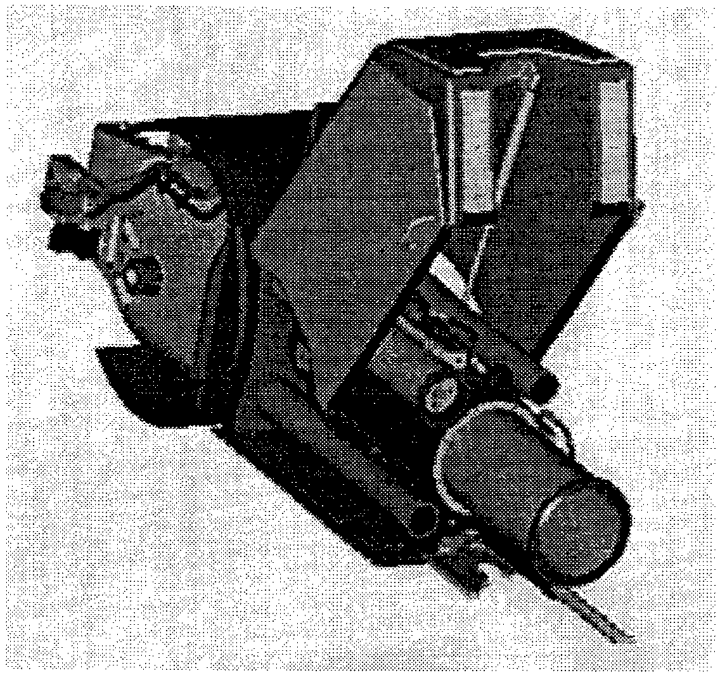

Figure 8. SMARTweave Was Implemented in the Production of the XM194 Ballistic Shield, Which Protects the Recoil and Cooling Mechanisms of the 155-mm Cannon.

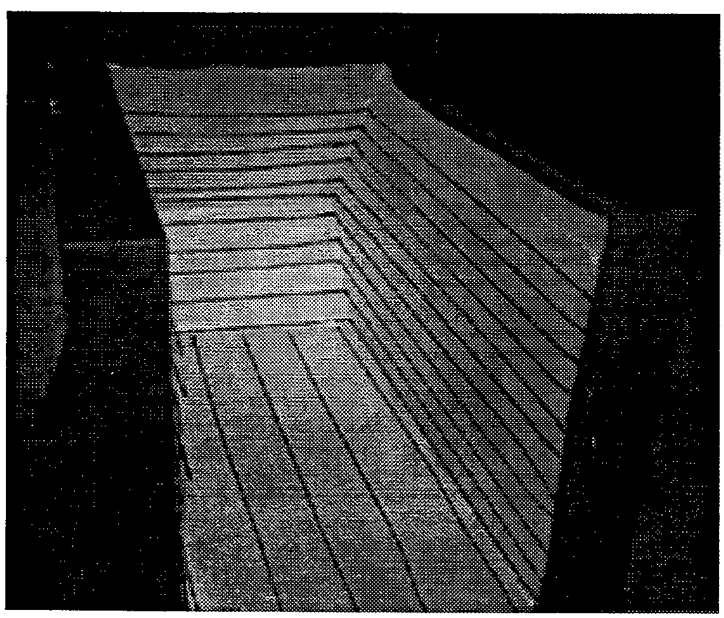

Figure 9. Female Tooling Used to Manufacture the Ballistic Shield With the First Several Layers of Glass Preform and the First Plane of Embedded SMARTweave Sensors Made of 12k Carbon Tows.

the sense lines. In this case, 12k carbon tows were used as sensors. Seven spiral tubes were placed along the length of the shield on the top layer, and the preform was bagged, as depicted in Figure 10. By placing the sensors near the tooling surface, the resin flow front at the tool may be monitored. The flow visualization was used in this case to control the inlet and vacuum ports. Initially, only the center of the seven tubes served as an inlet port and the remaining six drew a vacuum. As the resin reached the adjacent line, it was to be switched from a vacuum line to another injection source. One cannot rely on visual techniques to make this conversion. It has been shown at ARL that a dry line would result along the bottom of the part just before the injection source if the injection is begun to soon, since the top layer of resin did not correlate to the flow front at the tooling surface. Using SMARTweave to monitor the flow front, a through-thickness analysis could be achieved. With knowledge of the relative distances between the nodes, the software's flow diagram indicated when the resin had reached the next tube. At this point, the switch from vacuum port to resin injection was made.

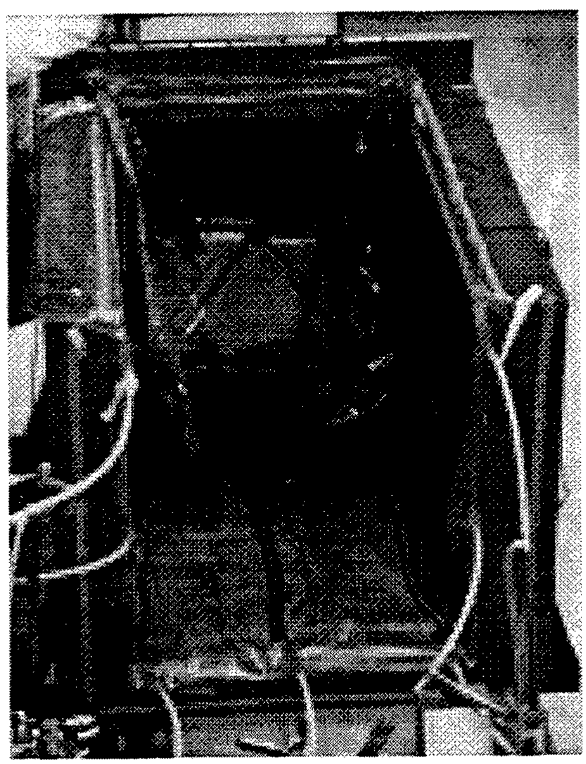

Figure 10. SMARTweave Was Used in the SCRIMP Process to Control the Infusion Ports and Vacuum Vents in the Manufacturing of the Ballistic Shield.

A sample voltage vs. time cure graph for the vinyl ester resin system used for the Ballistic Shield is found in Figure 11. In this case, unlike the epoxy, no external heat was added during the curing process. Therefore, the highest voltage signal correlated to the initial point of infusion, which had the least amount of crosslinking of the thermoset resin. The signal continued to decrease uniformly with time as the ions became more restricted in their movement. Figure 12 depicts the final ballistic shield, with the remaining embedded SMARTweave sensors.

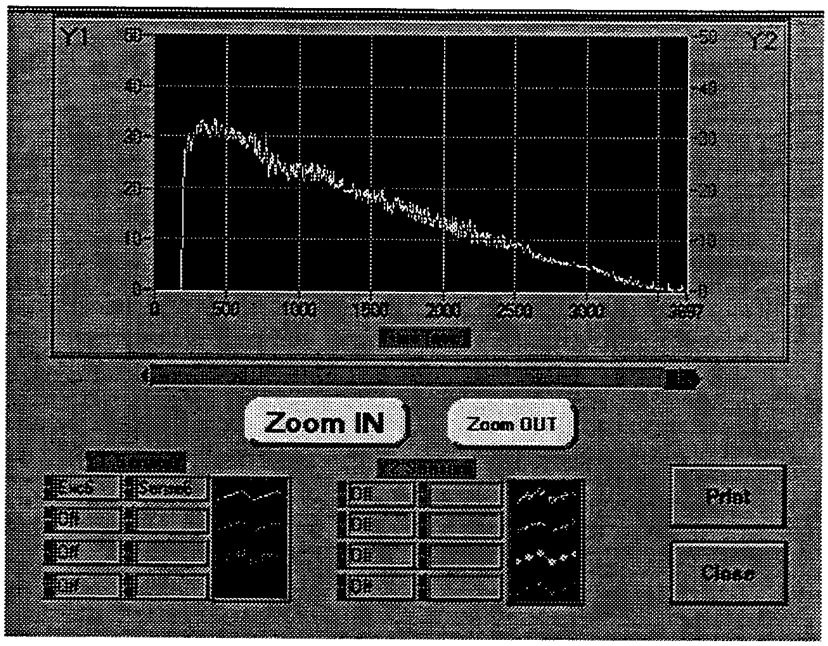

Figure 11. The Cure Graph Voltage vs. Time for a Single Node for the Vinyl Ester System That Was Used as a Matrix Material in the Ballistic Shield. The Part That Was Cured at Room Temperature Depicts a Steady Decrease in Voltage Signal as the Resin's Ionic Mobility Was Reduced.

6. Future Work

This work has shown two different advancements that will be investigated. The potential for SMARTweave to serve as a damage detection device has been shown first. As shown in Figure 13, the sensors, when broken, will register a change in resistance. Upon material advancements in sensor type, this application could be optimized to yield a thorough, health-monitoring system.

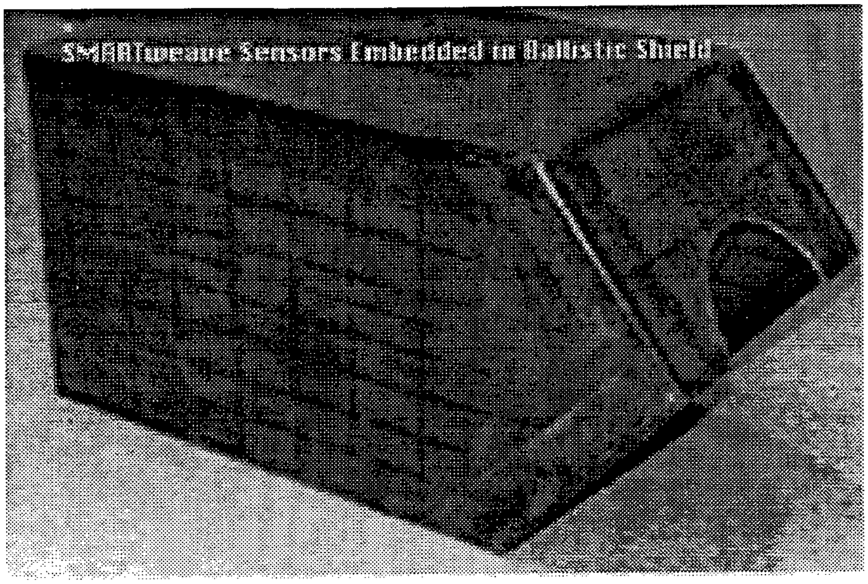

Figure 12. The Completed Quarter-Scale Thickness Prototype With 32 Embedded SMARTweave Sensors.

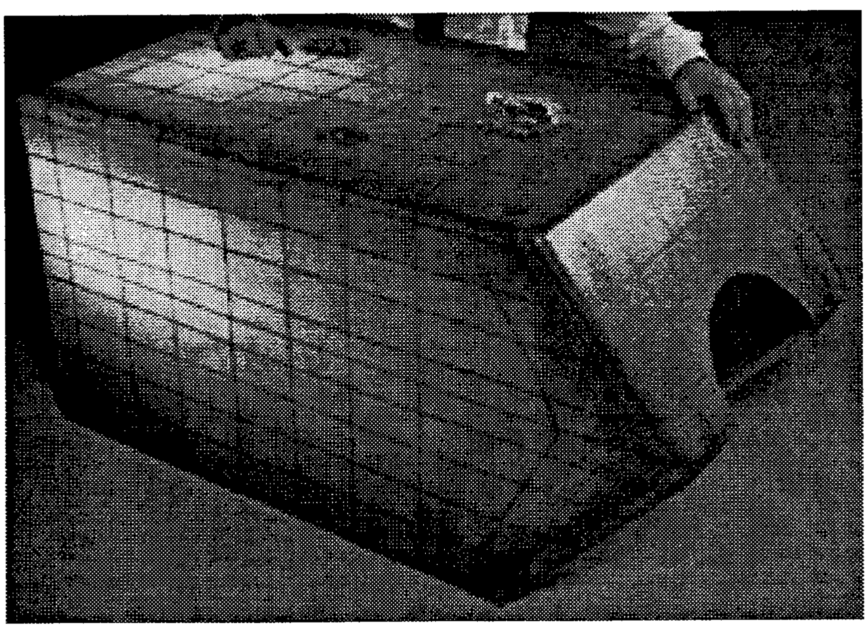

Figure 13. SMARTweave's Damage-Detection Capability, as Demonstrated by Ballistic Impacts on the XM194 Gun Mount Shield.

Second, similar processing on a male tool would have certain advantages to processing in a female tool, such as ease of lay-up. Based on that understanding, a male tool has been designed and attempts will be made to fabricate a Ballistic Shield.

7. Conclusions

In summary, SCRIMP is an excellent fabrication method for large-scale, thick-section composite materials, such as the XM194 gun mount shield. It has been shown that SMARTweave has numerous applications specifically related to composite process control. It may be used as a mechanism for both flow monitoring and control of the inlet and vacuum ports in a SCRIMP environment. Finally, several new areas of research have been founded, including damage detection and SCRIMP on a male tool. Overall, the prototyping of the XM194 gun mount shield has been a tremendous success.

8. Reference

1. Seeman, W. H. "Plastic Transfer Molding Techniques for the Production of Fiber Reinforced Plastic Structures." U.S. Patent No. 4, 902, 215, 20 February 1990.

2. Walsh, S. W. "In-Situ Sensor Method and Device." U.S. Patent No. 5, 210, 499, 11 May 1993.

INTENTIONALLY LEFT BLANK.

NO. OF COPIES	ORGANIZATION
2	DEFENSE TECHNICAL INFORMATION CENTER DTIC DDA 8725 JOHN J KINGMAN RD STE 0944 FT BELVOIR VA 22060-6218
1	HQDA DAMO FDQ DENNIS SCHMIDT 400 ARMY PENTAGON WASHINGTON DC 20310-0460
1	DPTY ASSIST SCY FOR R&T SARD TT F MILTON RM 3EA79 THE PENTAGON WASHINGTON DC 20310-0103
1	OSD OUSD(A&T)/ODDDR&E(R) R J TREW THE PENTAGON WASHINGTON DC 20301-7100
1	CECOM SP & TRRSTRL COMMCTN DIV AMSEL RD ST MC M H SOICHER FT MONMOUTH NJ 07703-5203
1	PRIN DPTY FOR TCHNLGY HQ US ARMY MATCOM AMCDCG T M FISETTE 5001 EISENHOWER AVE ALEXANDRIA VA 22333-0001
1	DPTY CG FOR RDE HQ US ARMY MATCOM AMCRD BG BEAUCHAMP 5001 EISENHOWER AVE ALEXANDRIA VA 22333-0001
1	INST FOR ADVNCD TCHNLGY THE UNIV OF TEXAS AT AUSTIN PO BOX 202797 AUSTIN TX 78720-2797

NO. OF COPIES	ORGANIZATION
1	GPS JOINT PROG OFC DIR COL J CLAY 2435 VELA WAY STE 1613 LOS ANGELES AFB CA 90245-5500
3	DARPA L STOTTS J PENNELLA B KASPAR 3701 N FAIRFAX DR ARLINGTON VA 22203-1714
1	US MILITARY ACADEMY MATH SCI CTR OF EXCELLENCE DEPT OF MATHEMATICAL SCI MDN A MAJ DON ENGEN THAYER HALL WEST POINT NY 10996-1786
1	DIRECTOR US ARMY RESEARCH LAB AMSRL CS AL TP 2800 POWDER MILL RD ADELPHI MD 20783-1145
1	DIRECTOR US ARMY RESEARCH LAB AMSRL CS AL TA 2800 POWDER MILL RD ADELPHI MD 20783-1145
3	DIRECTOR US ARMY RESEARCH LAB AMSRL CI LL 2800 POWDER MILL RD ADELPHI MD 20783-1145
	<u>ABERDEEN PROVING GROUND</u>
4	DIR USARL AMSRL CI LP (305)

NO. OF COPIES	ORGANIZATION
1	DIRECTOR USARL AMSRL CP CA D SNIDER 2800 POWDER MILL RD ADELPHI MD 20783
1	COMMANDER US ARMY ARDEC AMSTA AR FSE T GORA PICATINNY ARSENAL NJ 07806-5000
3	COMMANDER US ARMY ARDEC AMSTA AR TD R PRICE V LINDNER C SPINELLI PICATINNY ARSENAL NJ 07806-5000
5	US ARMY TACOM AMSTA JSK S GOODMAN J FLORENCE AMSTA TR D B RAJU L HINOJOSA D OSTBERG WARREN MI 48397-5000
5	PM SADARM SFAE GCSS SD COL B ELLIS M DEVINE W DEMASSI J PRITCHARD S HROWNAK PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY ARDEC F MCLAUGHLIN PICATINNY ARSENAL NJ 07806-5000

NO. OF COPIES	ORGANIZATION
5	COMMANDER US ARMY ARDEC AMSTA AR CCH S MUSALLI P CHRISTIAN R CARR M LUCIANO T LOUCEIRO PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY ARDEC AMSTA AR E FENNELL PICATINNY ARSENAL NJ 07805-5000
1	COMMANDER US ARMY ARDEC AMSTA AR CCH PICATINNY ARSENAL NJ 07806-5000
2	COMMANDER US ARMY ARDEC AMSTA AR PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY ARDEC AMSTA AR CCH P J LUTZ PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY ARDEC AMSTA AR FSF T C LIVECCHIA PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY ARDEC AMSTA AR QAC T/C C PATEL PICATINNY ARSENAL NJ 07806-5000

NO. OF COPIES	ORGANIZATION
2	COMMANDER US ARMY ARDEC AMSTA AR M D DEMELLA F DIORIO PICATINNY ARSENAL NJ 07806-5000
3	COMMANDER US ARMY ARDEC AMSTA AR FSA A WARNASH B MACHAK C CHIEFA PICATINNY ARSENAL NJ 07806-5000
8	DIRECTOR BENET LABORATORIES AMSTA AR CCB J KEANE J BATTAGLIA J VASILAKIS G FFIAR V MONTVORI J WRZOCHALSKI R HASENBEIN AMSTA AR CCB R S SOPOK WATERVLIET NJ 12189
1	COMMANDER SMCWV QAE Q B VANINA BLDG 44 WATERVLIET ARSENAL WATERVLIET NY 12189-4050
1	COMMANDER SMCWV SPM T MCCLOSKEY BLDG 253 WATERVLIET ARSENAL WATERVLIET NY 12189-4050
1	COMMANDER SMCWV QA QS K INSCO WATERVLIET ARSENAL WATERVLIET NY 12189-4050
1	COMMANDER US ARMY ARDEC AMSMC PBM K PICATINNY ARSENAL NJ 07806-5000

NO. OF COPIES	ORGANIZATION
1	COMMANDER US ARMY BELVOIR RD&E CTR STRBE JBC FORT BELVOIR VA 22060-5606
2	COMMANDER US ARMY ARDEC AMSTA AR FSP G M SCHIKSNIS D CARLUCCI PICATINNY ARSENAL NJ 07806-5000
1	US ARMY COLD REGIONS RSRCH & ENGRNG LAB P DUTTA 72 LYME RD HANOVER NH 03755
1	DIRECTOR USARL AMSRL WT L D WOODBURY 2800 POWDER MILL RD ADELPHI MD 20783-1145
3	COMMANDER US ARMY MISSILE CMD AMSMI RD W MCCORKLE AMSMI RD ST P DOYLE AMSMI RD ST CN T VANDIVER REDSTONE ARSENAL AL 35898-5247
2	US ARMY RSRCH OFC A CROWSON J CHANDRA PO BOX 12211 RESEARCH TRIANGLE PARK NC 27709-2211
5	PROJECT MANAGER TMAS SFAE GSSC TMA COL PAWLICKI K KIMKER E KOPACZ R ROESER B DORCY PICATINNY ARSENAL NJ 07806-5000

NO. OF COPIES	ORGANIZATION
1	PROJECT MANAGER TMAS SFAE GSSC TMA SMD R KOWALSKI PICATINNY ARSENAL NJ 07806-5000
2	PEO FIELD ARTILLERY SYS SFAE FAS PM H GOLDMAN T MCWILLIAMS PICATINNY ARSENAL NJ 07806-5000
2	PROJECT MGR CRUSADER G DELCOCO J SHIELDS PICATINNY ARSENAL NJ 07806-5000
2	NASA LANGLEY RSRCH CTR MS 266 AMSRL VS W ELBER F BARTLETT JR HAMPTON VA 23681-0001
2	COMMANDER DARPA J KELLY B WILCOX 3701 N FAIRFAX DR ARLINGTON VA 22203-1714
6	COMMANDER WRIGHT PATTERSON AIR FORCE BASE WL FIV A MAYER WL MLBM S DONALDSON T BENSON TOLLE C BROWNING J MCCOY F ABRAHAMS 2941 P ST STE 1 DAYTON OH 45433
1	NSW CTR DAHLGREN DIV CODE G06 DAHLGREN VA 22448

NO. OF COPIES	ORGANIZATION
1	NAVAL RSRCH LAB CODE 6383 I WOLOCK WASHINGTON DC 20375-5000
1	OFC OF NAVAL RSRCH MECH DIV CODE 1132SM YAPA RAJAPAKSE ARLINGTON VA 22217
1	NSW CTR CRANE DIV M JOHNSON CODE 20H4 LOUISVILLE KY 40214-5245
1	DAVID TAYLOR RSRCH CTR SHIP STRUCTURES & PROCTECTION DEPT J CORRADO CODE 1702 BETHESDA MD 20084
2	DAVID TAYLOR RSRCH CTR R ROCKWELL W PHYILLAIER BETHESDA MD 20054-5000
1	DEFENSE NUCLEAR AGENCY INNOVATIVE CONCEPTS DIV DR R ROHR 6801 TELEGRAPH RD ALEXANDRIA VA 22310-3398
1	DR FRANK SHOUP EXPEDITIONARY WARFARE DIV N85 2000 NAVY PENTAGON WASHINGTON DC 20350-2000
1	OFC OF NAVAL RSRCH D SIEGEL 351 800 N QUINCY ST ARLINGTON VA 22217-5660
1	JOSEPH H FRANCIS NSW CTR CODE G30 DAHLGREN VA 2248

NO. OF COPIES	ORGANIZATION
2	NSW CTR CODE G32 DON WILSON CODE G32 R D COOPER DAHLGREN VA 22448
4	NSW CTR CODE G33 JOHN FRAYSSE ELDRIDGE ROWE TOM DURAN LAURA DE SIMONE DAHLGREN VA 22448
1	COMMANDER NAVAL SEA SYS CMD D LIESE 2531 JEFFERSON DAVIS HWY ARLINGTON VA 22242-5160
1	NSW MARY E LACY CODE B02 17320 DAHLGREN RD DAHLGREN VA 22448
1	NSW TECH LIB CODE 323 17320 DAHLGREN RD DAHLGREN VA 22448
4	DIRECTOR LAWRENCE LIVERMORE NATL LAB R CHRISTENSEN S DETERESA F MAGNESS M FINGER PO BOX 808 LIVERMORE CA 94550
1	LOS ALAMOS NATL LAB F ADDESSIO MS B216 PO BOX 1633 LOS ALAMOS NM 87545
1	LOS ALAMOS NATL LAB R M DAVIS PO BOX 2008 OAK RIDGE TN 27831-6195

NO. OF COPIES	ORGANIZATION
1	PENN STATE UNIV C BAKIS 227 N HAMMOND UNIVERSITY PARK PA 16802
3	UDLP 4800 EAST RIVER RD P JANKE MS170 T GIOVANETTI MS236 B VAN WYK MS389 MINNEAPOLIS MN 55421-1498
4	DIRECTOR SANDIA NATL LAB APPLIED MECHANICS DEPT DIV 8241 W KAWAHARA K PERANO D DAWSON P NIELAN PO BOX 969 LIVERMORE CA 94550-0096
1	BATTELLE C R HARGREAVES 505 KING AVE COLUMBUS OH 43201-2681
1	PACIFIC NORTHWEST LAB M SMITH PO BOX 999 RICHLAND WA 99352
1	LAWRENCE LIVERMORE NATL LAB M MURPHY PO BOX 808 L282 LIVERMORE CA 94550
1	DREXEL UNIV ALBERT S D WANG 32ND & CHESTNUT ST PHILADELPHIA PA 19104
1	NC STATE UNIV CIVIL ENGRNG DEPT W RASDORF PO BOX 7908 RALEIGH NC 27696-7908

NO. OF COPIES	ORGANIZATION
1	PENN STATE UNIV RICHARD MCNITT 227 HAMMOND BLDG UNIVERSITY PARK PA 16802
1	PENN STATE UNIV RENATA ENGEL 245 HAMMOND BLDG UNIVERSITY PARK PA 16801
1	PURDUE UNIV SCHOOL OF AERO & ASTRO CT SUN W LAFAYETTE IN 47907-1282
1	STANFORD UNIV DEPT OF AERONAUTICS & AEROBALLISTICS DURANT BLDG S TSAI STANFORD CA 94305
1	UCLA MANE DEPT ENGR IV H THOMAS HAHN LOS ANGELES CA 90024-1597
2	UNIV OF DAYTON RSRCH INST RAN Y KIM AJIT K ROY 300 COLLEGE PARK AVE DAYTON OH 45469-0168
1	UNIVERSITY OF DAYTON JAMES M WHITNEY COLLEGE PARK AVE DAYTON OH 45469-0240
2	UNIV OF DE CTR FOR COMPOSITE MATERIALS J GILLESPIE M SANTARE 201 SPENCER LAB NEWARK DE 18716

NO. OF COPIES	ORGANIZATION
1	UNIV OF IL AT URBANA CHAMPAIGN NATL CTR FOR COMPOSITE MATERIALS RSRCH 216 TALBOT LAB J ECONOMY 104 S WRIGHT ST URBANA IL 61801
1	UNIV OF KY LYNN PENN 763 ANDERSON HALL LEXINGTON KY 40506-0046
1	UNIV OF UT DEPT OF MECH & INDUSTRIAL ENGR S SWANSON SALT LAKE CITY UT 84112
3	THE UNIV OF TX AT AUSTIN CTR FOR ELECTROMECHANICS J PRICE A WALLS J KITZMILLER 10100 BURNET RD AUSTIN TX 78758-4497
3	VPI AND STATE UNIV DEPT OF ESM M W HYER K REIFSNIDER R JONES BLACKSBURG VA 24061-0219
1	UNIV OF MD DR ANTHONY J VIZZINI DEPT OF AEROSPACE ENGRNG COLLEGE PARK MD 20742
1	AAI CORP DR T G STASTNY PO BOX 126 HUNT VALLEY MD 21030-0126
1	JOHN HEBERT PO BOX 1072 HUNT VALLEY MD 21030-0126

NO. OF COPIES	ORGANIZATION
1	ARMTEC DEFENSE PRODUCTS STEVE DYER 85 901 AVE 53 PO BOX 848 COACHELLA CA 92236
2	ADVANCED COMP MATERIALS CORP P HOOD J RHODES 1525 S BUNCOMBE RD GREER SC 29651-9208
1	SAIC DAN DAKIN 2200 POWELL ST STE 1090 EMERYVILLE CA 94608
1	SAIC MILES PALMER 2109 AIR PARK RD S E ALBUQUERQUE NM 87106
1	SAIC ROBERT ACEBAL 1225 JOHNSON FERRY RD STE 100 MARIETTA GA 30068
1	SAIC DR GEORGE CHRYSSOMALLIS 3800 W 80TH STREET STE 1090 BLOOMINGTON MN 55431
4	ALLIANT TECHSYSTEMS INC C CANDLAND R BECKER L LEE R LONG D KAMDAR G KASSUELKE 600 2ND ST NE HOPKINS MN 55343-8367
1	AMOCO PERFORMANCE PRODUCTS INC M MICHNO JR 4500 MCGINNIS FERRY RD ALPHARETTA GA 30202-3944

NO. OF COPIES	ORGANIZATION
1	APPLIED COMPOSITES W GRISCH 333 NORTH SIXTH ST ST CHARLES IL 60174
1	BRUNSWICK DEFENSE T HARRIS STE 410 1745 JEFFERSON DAVIS HWY ARLINGTON VA 22202
1	PROJECTILE TECHNOLOGY INC 515 GILES ST HAVRE DE GRACE MD 21078
1	CUSTOM ANALYTICAL ENGR SYS INC A ALEXANDER 13000 TENSOR LANE NE FLINTSTONE MD 21530
1	NOESIS INC ALLEN BOUTZ 1110 N GLEBE RD STE 250 ARLINGTON VA 22201-4795
1	ARROW TECH ASSO 1233 SHELBURNE RD STE D 8 SOUTH BURLINGTON VT 05403-7700
1	NSWC R HUBBARD G33 C DAHLGREN DIV DAHLGREN VA 22448-5000
5	GEN CORP AEROJET D PILLASCH T COULTER C FLYNN D RUBAREZUL M GREINER 1100 WEST HOLLYVALE ST AZUSA CA 91702-0296

NO. OF COPIES	ORGANIZATION
7	CIVIL ENGR RSRCH FOUNDATION H BERNSTEIN PRESIDENT C MAGNELL K ALMOND R BELLE M WILLETT E DELO B MATTES 1015 15TH ST NW STE 600 WASHINGTON DC 20005
1	NIST STRCTRE & MCHNCS GROUP POLYMER DIV POLYMERS RM A209 GREGORY MCKENNA GAITHERSBURG MD 20899
1	DUPONT COMPANY COMPOSITES ARAMID FIBERS S BORLESKE DVLPMNT MGR CHESNUT RUN PLAZA PO BOX 80702 WILMINGTON DE 19880-0702
1	GENERAL DYNAMICS LAND SYSTEMS DIVISION D BARTLE PO BOX 1901 WARREN MI 48090
3	HERCULES INC R BOE F POLICELLI J POESCH PO BOX 98 MAGNA UT 84044
3	HERCULES INC G KUEBELER J VERMEYCHUK B MANDERVILLE JR HERCULES PLZ WILMINGTON DE 19894
1	HEXCEL M SHELENDICH 11555 DUBLIN BLVD PO BOX 2312 DUBLIN CA 94568-0705

NO. OF COPIES	ORGANIZATION
1	IAP RESEARCH INC A CHALLITA 2763 CULVER AVE DAYTON OH 45429
5	INSTITUTE FOR ADVANCED TECH T KIEHNE H FAIR P SULLIVAN W REINECKE I MCNAB 4030 2 W BRAKER LN AUSTIN TX 78759
1	INTEGRATED COMPOSITE TECH H PERKINSON JR PO BOX 397 YORK NEW SALEM PA 17371-0397
1	INTERFEROMETRICS INC R LARRIVA VICE PRESIDENT 8150 LEESBURG PIKE VIENNA VA 22100
1	AEROSPACE RES & DEV (ASRDD) CORP D ELDER PO BOX 49472 COLORADO SPRINGS CO 80949-9472
1	PM ADVANCED CONCEPTS LORAL VOUGHT SYSTEMS J TAYLOR PO BOX 650003 MS WT 21 DALLAS TX 76265-0003
2	LORAL VOUGHT SYSTEMS G JACKSON K COOK 1701 W MARSHALL DR GRAND PRAIRIE TX 75051
1	BRIGS CO JOE BACKOFEN 2668 PETERBOROUGH ST HERDON VA 22071-2443

NO. OF COPIES	ORGANIZATION
1	SOUTHWEST RSRCH INSTITUTE JACK RIEGEL ENGRG & MTRL SCIENCES DIV 6220 CULEBRA RD PO DRAWER 28510 SAN ANTONIO TX 78228-0510
1	ZERNOW TECHNICAL SERVICES LOUIS ZERNOW 425 W BONITA AVE SUITE 208 SAN DIMAS CA 91773
1	ROBERT EICHELBERGER CONSULTANT 409 W CATHERINE ST BEL AIR MD 21014-3613
1	DYNA EAST CORPORATION PEI CHI CHOU 3201 ARCH ST PHILADELPHIA PA 19104-2711
2	MARTIN MARIETTA CORP P DEWAR L SPONAR 230 EAST GODDARD BLVD KING OF PRUSSIA PA 19406
2	OLIN CORPORATION FLINCHBAUGH DIV E STEINER B STEWART PO BOX 127 RED LION PA 17356
1	OLIN CORPORATION L WHITMORE 10101 9TH ST NORTH ST PETERBURG FL 33702
1	RENNSAELER PLYTCHNC INST R B PIPES PRESIDENT OFC PITTSBURGH BLDG TROY NY 12180-3590
1	SPARTA INC J GLATZ 9455 TOWNE CTR DRIVE SAN DIEGO CA 92121-1964

NO. OF COPIES	ORGANIZATION
2	UNITED DEFENSE LP P PARA G THOMAS 1107 COLEMAN AVE BOX 367 SAN JOSE CA 95103
1	MARINE CORPS SYSTEMS CMD PROGRAM MGR GROUND WPNS COL RICK OWEN 2083 BARNETT AVE SUITE 315 QUANTICO VA 22134-5000
1	OFFICE OF NAVAL RES J KELLY 800 NORTH QUINCEY ST ARLINGTON VA 22217-5000
2	NSWC CARDEROCK DIV R CRANE CODE 2802 C WILLIAMS CODE 6553 3A LEGGETT CIR ANNAPOLIS MD 21402
5	SIKORSKY H BUTTS T CARSTENSAN B KAY S GARBO J ADELMANN 6900 MAIN ST PO BOX 9729 STRATFORD CT 06601-1381
1	D ADAMS U WYOMING PO BOX 3295 LARAMIE WY 82071
1	MICHIGAN ST UNIVERSITY R AVERILL 3515 EB MSM DEPT EAST LANSING MI 48824-1226
1	AMOCO POLYMERS J BANISAUKAS 4500 MCGINNIS FERRY RD ALPHARETTA GA 30005

NO. OF COPIES	ORGANIZATION
1	HEXCEL T BITZER 11711 DUBLIN BLVD DUBLIN CA 94568
1	BOEING R BOHLMANN PO BOX 516 MC 5021322 ST LOUIS MO 63166-0516
1	NAVSEA OJRI G CAMPONESCHI 2351 JEFFERSON DAVIS HWY ARLINGTON VA 22242-5160
1	LOCKHEED MARTIN R FIELDS 1195 IRWIN CT WINTER SPRINGS FL 32708
1	USAF WL/MLS OL A HAKIM 5225 BAILEY LOOP 243E MCCLELLAN AFB CA 55552
1	PRATT & WHITNEY D HAMBRICK 400 MAIN ST MS 114 37 EAST HARTFORD CT 06108
1	DOUGLAS PRODUCTS DIV BOEING L J HART-SMITH 3855 LAKEWOOD BLVD D800-0019 LONG BEACH CA 90846-0001
1	MIT P LAGACE 77 MASS AVE CAMBRIDGE MA 01887
1	NASA LANGLEY J MASTERS MS 389 HAMPTON VA 23662-5225

NO. OF COPIES	ORGANIZATION
1	CYTEC M LIN 1440 N KRAEMER BLVD ANAHEIM CA 92806
2	BOEING ROTORCRAFT P MINGURT P HANDEL 800 B PUTNAM BLVD WALLINGFORD PA 19086
2	FAA TECH CENTER D OPLINGER AAR 431 P SHYPRYKEVICH AAR 431 ATLANTIC CITY INTL AIRPORT NJ 08405
1	NASA LANGLEY RC CC POE MS 188E NEWPORT NEWS VA 23608
1	LOCKHEED MARTIN S REEVE 8650 COBB DR D/73-62 MZ 0648 MARIETTA GA 30063-0648
1	WL/MLBC E SHINN 2941 PST STE 1 WRIGHT PATTERSON AFB OH 45433-7750
2	IIT RESEARCH CENTER D ROSE 201 MILL ST ROME NY 13440-6916
1	MATERIALS SCIENCES CORP BW ROSEN 500 OFFICE CENTER DR STE 250 FT WASHINGTON PA 19034
1	DOW UT S TIDRICK 15 STERLING DR WALLINGFORD CT 06492

NO. OF COPIES	ORGANIZATION
3	TUSKEGEE UNIVERSITY MATERIALS RSRCH LAB SCHOOL OF ENGR & ARCH S JEELANI H MAHFUZ U VAIDYA TUSKEGEE AL 36088
4	NIST R PARNAS J DUNKERS M VANLANDINGHAM D HUNSTON POLYMERS DIVISION GAITHERSBURG MD 20899
2	NORTHROP GRUMMAN ENVIRONMENTAL PROGRAMS R OSTERMAN 8900 E WASHINGTON BLVD PICO RIVERA CA 90660
1	OAK RIDGE NATL LAB A WERESZCZAK BLDG 4515 MS 6069 PO BOX 2008 OAKRIDGE TN 37831-6064
1	COMMANDER US ARMY ARDEC T SACHAR INDUSTRIAL ECOLOGY CTR BLDG 172 PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER USA ATCOM AVIATION APPLIED TECH DIR J SCHUCK FORT EUSTIS VA 23604-1104
1	COMMANDER US ARMY ARDEC AMSTA AR SRE D YEE PICATINNY ARSENAL NJ 07806-5000

NO. OF COPIES	ORGANIZATION
7	COMMANDER US ARMY ARDEC AMSTA AR CCH B B KONRAD E RIVERA G EUSTICE S PATEL G WAGNECZ R SAYER F CHANG BLDG 65 PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY ARDEC AMSTA AR QAC T D RIGOGLIOSO BLDG 354 M829E3 IPT PICATINNY ARSENAL NJ 07806-5000
	ABERDEEN PROVING GROUND
75	DIR USARL AMSRL CI C NIETUBICZ 394 AMSRL CI C W STUREK 1121 AMSRL CI CB R KASTE 394 AMSRL CI S A MARK 309 AMSRL SL B AMSRL SL BA AMSRL SL BE D BELY 328 AMSRL WM B A HORST 390A E SCHMIDT 390A AMSRL WM BE G KELLER 390 C LEVERITT 390 D KOOKER 390A AMSRL WM BC P PLOSTINS 390 D LYON 390 J NEWILL 390 S WILKERSON 390 AMSRL WM BD R FIFER 390 B FORCH 390A R PESCE-RODRIGUEZ 390 B RICE 390A

NO. OF
COPIES ORGANIZATION

AMSRL WM
D VIECHNICK 4600
G HAGNAUER 4600
J MCCAULEY 4600
AMSRL WM MA
R SHUFORD 4600
S MCKNIGHT 4600
AMSRL WM MB
B BURNS 4600
W DRYSDALE 4600
J BENDER 4600
T BLANAS 4600
T BOGETTI 4600
R BOSSOLI 120
L BURTON 4600
J CONNORS 4600
S CORNELISON 120
P DEHMER 4600
R BOOLEY 4600
B FINK 4600
G GAZONAS 4600
S GHIORSE 4600
D GRANVILLE 4600
D HOPKINS 4600
C HOPPEL 4600
D HENRY 4600
R KASTE 4600
R KLINGER 4600
M LEADORE 4600
R LIEB 4600
E RIGAS 4600
D SPAGNUOLO 4600
W SPURGEON 4600
J TZENG 4600
AMSRL WM MB ALC
A ABRAHAMIAN
M BERMAN
A FRYDMAN
T LI
W MCINTOSH
E SZYMANSKI
AMSRL WM MC T HYNES 4600
AMSRL WM MD W ROY 4600
AMSRL WM ME R ADLER 4600
AMSRL WM T W MORRISON 309
AMSRL WM TA
W GILLICH 393
W BRUCHEY 393
T HAVEL 393
AMSRL WM TC
R COATES 309
W DE ROSSET 309
AMSRL WM TD
T CHOU 4600
D DIETRICH 309
A DAS GUPTA 309
AMSRL WM TE J POWELL 120
AMSRL WM BA
F BRANDON 120
W D AMICO 120
AMSRL WM BB J BORNSTEIN 120
AMSRL WM BC A ZIELINSKI 390
AMSRL WM BF J LACETERA 120

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	July 1998	Final, Dec 95 - Dec 97

4. TITLE AND SUBTITLE
XM194 Gun Mount Shield: Processing in a Female Tool Utilizing Embedded Sensors for Process Control

5. FUNDING NUMBERS
COMP02

6. AUTHOR(S)
William O. Ballata, J. Robert Klinger, and Shawn M. Walsh

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Research Laboratory
ATTN: AMSRL-WM-MD
Aberdeen Proving Ground, MD 21005-5069

8. PERFORMING ORGANIZATION REPORT NUMBER
ARL-TR-1710

9. SPONSORING/MONITORING AGENCY NAMES(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This report addresses the use of U.S. Army Research Laboratory (ARL) and industry technologies to prototype the XM194 gun mount shield. The prototyping was done with novel ideas and techniques in mind. It was used as an advanced technology demonstrator for sensor-based process control. First, a brief description of the XM194 gun mount shield is given. Second, Seemann's Composite Resin Infusion Molding Process (SCRIMP) was used as a fabrication process, which is possible through the establishment of a Cooperative Research and Development Agreement (CRADA) with SCRIMP Systems, Inc. Third, the state-of-the-art Sensors Mounted as Roving Threads (SMARTweave) system is detailed, along with the sensor-based control methodology utilized in the process. Fourth, the successful processing of the XM194 gun mount shield is illustrated. Finally, several possibilities for future sensor process and process control work are discussed.

14. SUBJECT TERMS	15. NUMBER OF PAGES
XM194 gun mount shield, SCRIMP, SMARTweave, RTM	31
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18 298-102

INTENTIONALLY LEFT BLANK.

USER EVALUATION SHEET/CHANGE OF ADDRESS

This Laboratory undertakes a continuing effort to improve the quality of the reports it publishes. Your comments/answers to the items/questions below will aid us in our efforts.

1. ARL Report Number/Author ARL-TR-1710 (Ballata) Date of Report July 1998

2. Date Report Received ______

3. Does this report satisfy a need? (Comment on purpose, related project, or other area of interest for which the report will be used.) ______

4. Specifically, how is the report being used? (Information source, design data, procedure, source of ideas, etc.) ______

5. Has the information in this report led to any quantitative savings as far as man-hours or dollars saved, operating costs avoided, or efficiencies achieved, etc? If so, please elaborate. ______

6. General Comments. What do you think should be changed to improve future reports? (Indicate changes to organization, technical content, format, etc.) ______

CURRENT ADDRESS

Organization

Name E-mail Name

Street or P.O. Box No.

City, State, Zip Code

7. If indicating a Change of Address or Address Correction, please provide the Current or Correct address above and the Old or Incorrect address below.

OLD ADDRESS

Organization

Name

Street or P.O. Box No.

City, State, Zip Code

(Remove this sheet, fold as indicated, tape closed, and mail.)

(DO NOT STAPLE)